A review of biomechanical studies on stoop and squat lifting

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A REVIEW OF BIOMECHANICAL STUDIES ON STOOP AND SQUAT LIFTING

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To assess the rationale of advocating the squat as opposed to the stoop technique, biomechanical studies comparing the two were reviewed. With the exception of some specific lifting tasks, net moments and compression forces were estimated to be equal or higher in squat lifting. Shear force and spinal bending moments appeared lower in squat lifting. Net moments and compression forces probably can cause injury, whereas the other load components remain below injury threshold. In conclusion, the literature does not provide support for advocating squat lifting.

INTRODUCTION

Recently, Volinn (1999) has argued that studies designed after randomised clinical trials are needed to prove the effectiveness of ergonomics interventions with respect to low back pain (LBP) prevention. Indeed an 'evidence-based' ergonomics practice seems overdue. However, given the high costs involved with this type of studies ample consideration of the risk factors addressed and preventive strategy implemented is necessary. Several recent epidemiological review studies conclude that lifting is the best documented risk factor for LBP (Burdorf & Sorock, 1997; Ferguson & Marras, 1997; Frank et al., 1996; Kuiper et al., in press). In line with this, it would seem appropriate to consider preventive strategies involving measures aimed at reducing back load associated with lifting tasks.

In practice, administrative controls such as training and instruction in particular with respect to lifting technique are widely used (Chavalinitikul, Nopteepkangwan, & Kanjanopas, 1995; Lagerstrom, Josephson, Pingel, Tjernstrom, & Hagberg, 1998; Nevalapuranen, 1996; Nygard, Merisalo, Arola, Manka, & Huhtala, 1998; Schenk, Doran, & Stachura, 1996; St-Vincent, Tellier, & Lortie, 1989; Videman et al., 1989). The most commonly advised lifting technique is the so-called squat technique or leg lift, in which the back remains as erect as possible and in which the knees are flexed (Garg & Moore, 1992). However, biomechanical studies have shown conflicting results on the effectiveness of this technique. The aim of the present review, therefore, was to evaluate the evidence that the lifting technique is an important determinant of the mechanical load during lifting. This review was limited to studies comparing symmetric stoop and squat lifting, as these are well defined and frequently studied techniques in manual materials handling.

METHODS

This review was based on a literature search in the several electronic databases. The references were screened on the basis of titles and abstracts. The literature retrieved was supplemented with references from reviews with a somewhat broader scope (Hsiang, Brogmus, & Courtney, 1997; Kroemer, 1992; Yu, Roht, Wise, Kilian, & Weir, 1984) and studies cited in the previously retrieved papers.

It is unknown what structures are responsible for LBP, and it seems likely that different structures may be involved in different cases. Therefore, all mechanical loads likely to induce injury to structures in the low back will be considered, this includes loads on spinal structures (e.g. ligaments, intervertebral disc, vertebrae) and musculotendinous structures (e.g. muscle, musculotendinous junction, tendinous insertion). Muscular damage is most likely to occur when high forces are sustained or produced repeatedly. The mechanical load on the osteoligamentous spine during symmetric lifting consist of three components: compression, shear and bending, each of which according to in vitro studies has the potential to cause injury (Adams, Green, & Dolan, 1994a; Adams & Hutton, 1982; Brinckmann, Biggeman, & Hilweg, 1989; Cyron, Hutton, & Troup, 1976; Lamy, Bazergui, Kraus, & Farfan, 1975; Perey, 1957; Yingling & McGill, 1999). Unfortunately, none of the four variables of interest can be measured directly. Therefore, we considered indicators of these parameters, based on model calculations, including net moments, estimated muscle forces or muscle moments, estimated compression and shear forces, and predicted bending moments resisted by the osteoligamentous spine, or tensile forces in individual ligaments.

RESULTS

In total 25 studies comparing stoop and squat lifting with respect to the mechanical load on the back were included in this review (Anderson & Chaffin, 1986; Buseck, Schipplein, Andersson, & Andriacchi, 1988; Bush-Joseph, Schipplein, Andersson, & Andriacchi, 1988; Chaffin & Page, 1994; Dieën, Creemers, Draisma, Toussaint, & Kingma, 1994; Dolan, Earley, & Adams, 1994a; Dolan, Mannion, & Adams, 1994b; Ekholm, Arborelius, & Nemeth, 1982; Garg & Herrin, 1979; Hagen & Harmsringdahl, 1994; Kjellberg, Lindbeck, & Hagberg, 1988; Leskinen, 1985; Leskinen, Stalhammar, Kuorinka, & Troup, 1983; Lindbeck & Arborelius, 1991; Looze, Dolan, Kingma, & Baten, 1998; Looze, Kingma, Thunnissen, Vanwijk, & Toussaint, 1994; Mittal & Malik, 1991; Park & Chaffin, 1974; Potvin, McGill, & Norman, 1991a; Potvin, Norman, Eckenrath, McGill, & Bennet, 1992; Toussaint, Baar, Langen, Looze, & Dieën, 1992; Toussaint, Commissaris, & Beek, 1997; Troup, Leskinen, Stålhammar, & Kuorinka, 1983; Wax, Flenghi, & Meyer, 1987). In several studies the comparison of the techniques was confounded with the horizontal distance (Ekholm et al., 1982; Garg & Herrin, 1979; Mittal & Malik, 1991; Wax et al., 1987), the mass lifted (Mittal & Malik, 1991), or the velocity of lifting (Buseck et al., 1988; Dieën et al., 1994).

The studies using a static linked segment model (LSM) to estimate the net moment yielded varying results. The majority of studies predicted a substantial reduction (10 to 34%) in back load when using the squat technique in at least one of the experimental conditions. However, two of these studies (Ekholm et al., 1982; Garg & Herrin, 1979), showed that when horizontal distance is constant the effect of technique disappears. The thirteen studies in which the net moment or extensor moment was estimated using dynamic analysis techniques found back loads in the two techniques to be either significantly higher (4 to 18%) in squat lifting or not significantly different. In eleven of these studies, the loads were lifted from a position in front of the feet. In three studies the horizontal position of the load was not described, nor could it be derived from any of the figures. Two studies did not report whether the differences found were significant. One of these did report a substantially lower (13%) net moment in squat lifting, but actually compared to a free technique, which was performed at a substantially higher velocity.

Overall, the studies providing compression force estimates yielded results in line with those of the moment estimates described above (Anderson & Chaffin, 1986; Chaffin & Page, 1994; Leskinen, 1985; Leskinen et al., 1983; Potvin et al., 1991a; Potvin et al., 1992; Troup et al., 1983). Most of these studies used fairly crude anatomical models of the lumbar spinal musculature or were based on predicted or statically analysed kinematics The two studies (Potvin et al., 1991a; Potvin et al., 1992) using a detailed anatomical model and dynamically calculated net moments indicated higher compression in squat lifting.

Shear forcess reported in one study only (Potvin et al., 1991a), were higher in stoop lifting than in squat lifting, as were bending moments (and ligament stresses) (Anderson & Chaffin, 1986; Dolan et al., 1994a; Dolan et al., 1994b).

DISCUSSION

Positive effects of squat lifting with respect to estimated moments and compression forces were found only when squat lifting allowed for lifting from a position between the feet. In practice, lifting from a position between the feet is often not possible and these results thus appear to be valid for a limited range of tasks. Actually in a study by Dieën et al. (1994), subjects lifting a barbell preferred a larger horizontal distance when using a squat technique as compared to a stoop technique. In addition, all studies showing this benefit of squat lifting used a static LSM. Hence the validity of the positive findings on squat lifting in these cases may be questioned. A striking finding in this respect is the fact that the positive effect of squat lifting in one study disappeared, when reanalysing the same data using a dynamic LSM (Lindbeck & Arborelius, 1991).

In lifting tasks where the load is not lifted from a position between the feet, the net moment and compression tended to be lower using the stoop technique. In contrast, in all studies reporting shear and bending moments, these were higher in stoop lifting. Consequently, the parameters of back load these indicators stand for need to be weighted with respect to each other. When a parameter increases with a change in lifting technique, but remains well below injury threshold, this increase can be considered of little importance. Thus the injury potential of the parameters of back load could be used to obtain such a weighting.

The net moments in lifting are within the range of the maximum isometric moments of healthy male subjects (Dieën, 1996; Dieën, Böke, Oosterhuis, & Toussaint, 1996; Dieën & Heijblom, 1996; Dieën, Oude Vrielink, Housheer, Lötters, & Toussaint, 1993) and probably above the strength of inactive males or older populations (Chaffin & Andersson, 1991; Dieën & Heijblom, 1996; McNeill, Warwick, & Andersson, 1980). The incidence of back injuries appears to increase when lifting moments exceed the isometric strength (Chaffin & Park, 1973; Herrin, Jaraiedi, & Anderson, 1986).

Compression forces of 3 to 5 kN, as occur during lifting, are high enough to cause failure in females over 20 and in males over 40 years old (Jäger & Luttmann, 1997) and probably in younger males under repetitive loading (Brinckmann, Biggeman, & Hilweg, 1988; Hansson, Keller., & Spengler, 1987). In the context of the comparison of stoop and squat lifting, it is important to note that compression strength is not significantly affected by flexion of the motion segment (Adams, McNally, Chinn, & Dolan, 1994b). It has been hypothesised that a major proportion of all LBP cases is attributable to excessive compression during tasks such as lifting (Dieën, Weinans, & Toussaint, 1999), which is supported by recent epidemiological research (Granata & Marras, 1999). Shear forces reported in one study only. were below strength values (Cyron et al., 1976; Lamy et al., 1975), suggesting that shear forces during lifting do not pose a serious injury risk (Cyron et al., 1976). However, it should be kept in mind that in repetitive loading lower shear forces may cause damage (Cyron & Hutton, 1981) and shear forces estimates during lifting are strongly dependent on the functional and anatomical assumptions in the model used (Dieën & Looze, 1999; Potvin, Norman, & McGill, 1991b). The bending moments carried by the osteoligamentous spine during lifting generally remain well below the injury threshold (Adams & Hutton, 1986; Dolan et al., 1994a). In conclusion, the conclusion based on net moments and compression forces are definitely relevant, whereas the relevance of shear remains to be shown and bending moments appear to be of little importance.

In conclusion, the present review shows that there is no substantial biomechanical evidence to support training and instruction in which the squat technique is advocated. Evidence obtained with other approaches such as psychophysics and exercise physiology, generally appears to support this conclusion (Duplessis et al., 1998; Garg & Herrin, 1979; Hagen, Hallen, & Harms-Ringdahl, 1993; Kumar, 1984; Welbergen, Kemper, Knibbe, Toussaint, & Clijssen, 1991). It is, therefore, suggested that further study of controls for preventing low back pain should be focussed on other aspects of lifting.

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